Vibration Bispectral Analysis for Fault Detection and Diagnoses of Rotating Mechanical Systems

A Thesis Submitted In Partial Fulfillment of

The Requirement for The Degree of

Master of Science

In

Electrical Engineering

Electronics and Communication Engineering

By

Michael RefaatHabibWasef

Under the supervision of

Dr. Rania Ahmed AbulSeoud

Associate Professor

Electrical Engineering Department

Faculty of Engineering, Fayoum University

Dr. Mohammed Ahmed Hassan

Assistant professor

Electrical Engineering Department

Faculty of Engineering, Fayoum University

Faculty of Engineering, Fayoum University

Fayoum, Egypt

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Approved By The Examining Committee:

1- **Associate Prof. Rania Ahmed AbulSeoud**
2- **Prof. AmrRefaatGody**
3- **Associate Prof. Ahmed Madian**

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Associate Prof. Rania Ahmed AbulSeoud (Member) Signature:…………………………

Prof.AmrRefaatGody(Internal Examiner)) Signature:…………………………

Associate Prof.Ahmed Madian(External Examiner) Signature:…………………………

Faculty of Engineering, Fayoum University

Fayoum, Egypt

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Abstract

Condition monitoring and fault diagnosis in rotorcrafts have significant effect on improving safety level and reducing operational and maintenance costs. In this thesis, advanced signal processing techniques and machine learning algorithms have been used to improve the performance of fault detection and diagnosis for critical rotating components in the AH-64D helicopter tail rotor drive train system. Currently, condition monitoring of rotating machinery is mostly based on vibration signals using first order spectral techniques such as auto and cross power spectrum which have limited performance. The idea of using bispectral analysis in condition monitoring has shown some benefits such as capturing second order nonlinearities in the system. However, this technique requires more experience and human efforts in order to correctly interpret results and categorize fault cases. Machine learning algorithms can be used with bispectral signal processing techniques in order to improve the fault detection and classification accuracy, reduce the complexity and speed up fault detection and classification process.

In this thesis, condition of the tail rotor drive shafts in the AH-64D helicopter is investigated using vibration signals simultaneously collected from two accelerometer sensors at the supporting hanger bearings. First, features extracted directly from auto and cross power

spectrum and bispectrum are used to classify three different seeded shaft faults compared to baseline case, namely: 1) - shaft misalignment, 2)- shaft imbalance, and 3)- combination of shaft misalignment and imbalance. Fault classification using features directly extracted from power spectrum or bispectrum uses large number of features and more complex calculation to calculate power spectrum or bispectrum for all the frequency range of the vibration signal. To improve the performance of the algorithm, wavelet decomposition is used to achieve multiresolution signal analysis and to denoise signal. The effect of multiresolution wavelet decomposition is studied first through the ability of the shaft main frequency and its harmonics to classify faults before and after wavelet decomposition. Search algorithm chooses indicative features which are applied to Neuro- Fuzzy system. Then, Shannon entropy is used to determine the most informative part in the signal. The most informative part is used to extract features using cross bispectrum. The extracted features are then fed to search algorithm which selects the most indicative features. In order to quantitatively evaluate the proposed method, different classifier are compared against each other such as linear discriminant analysis, quadratic discriminant analysis, support vector machine, multiclass logistic regression and trained neural network. Comparison criteria include accuracy, precision, sensitivity, F score, true alarm, and error classification accuracy (ECA). Comparing results from the four algorithms shows that using wavelet decomposition before spectral analysis (power spectrum or bispectrum) and search algorithm improves the classification accuracy and speeds up classification process.

Finally, the effect of torque variation on tail rotor drive shaft has been investigated. Vibration used in this part is measured at different torque values simulating different loads on the tail rotor. At each load value, vibration is measured using four sensors distributed over the tail rotor drive train. The proposed method depends on simulating a finite state machine where each state represents a load value among five different applied loads. Within each state, tail rotor drive train condition is modeled using parameters extracted form cross correlations among the four accelerometer sensors. Fuzzy logic is then used to cover the transition regions between states. Fuzzy logic uses three features which are selected using a proposed search algorithm from large number of features calculated from the vibration bispectrum. In order to quantitatively evaluate the proposed method, collected vibration signals are divided into training and testing samples. Training samples were used to train the fuzzy logic system, while testing samples are used to evaluate its performance. The proposed algorithm shows an interesting performance in determining the vibration behavior during torque variation on the TRDT parts.

Vibration data used in this thesis are collected from a dedicated AH-64D helicopter drive-train research test bed at the center of predictive maintenance (CPM), University of South Carolina, where experimental tests are conducted.

KEYWORDS:

AH-64D helicopter, Bispectrum, Condition based maintenance, Fault detection, Finite state machine, Fuzzy logic, Machine learning, Neural network, Power spectrum, Rotating machinery, Shafts, Vibration analysis, , Shannon entropy, Wavelet analysis.